

MEMORANDUM

ACTION - 6584

NATIONAL SECURITY COUNCIL

January 18, 1974

MEMORANDUM FOR: SECRETARY KISSINGER  
FROM: DAVID D. ELLIOTT *D.E.*  
SUBJECT: Report on Energy R&D

On the occasion of the President's meeting with his Foreign Intelligence Advisory Board (PFIAB) in October, he asked for views on an appropriate FY 75 energy R&D budget. In response, Edward Teller and John Foster authored an energy report (Tab C) which offers an example of such a budget and also reviews the possibilities and problems associated with several energy areas.

Information copies of the report were sent to Dr. Ray and Mr. Simon.

RECOMMENDATIONS:

1. That you sign the memorandum summarizing the PFIAB report for the President (Tab I);
2. That you sign the memorandum for Admiral Anderson and the contributing members of the PFIAB (Tab A).

THE WHITE HOUSE  
 WASHINGTON

MEMORANDUM FOR: THE PRESIDENT  
 FROM: HENRY A. KISSINGER  
 SUBJECT: Report on Energy R&D

In response to your request, your Foreign Intelligence Advisory Board (PFIAB) has submitted a short report (Tab C) on the prospects for R&D to help in the solution of our energy problems and has offered an example of an appropriate FY 75 budget (Tab B). This energy R&D budget is summarized below and contrasted to the proposal of Chairman Ray.

	<u>PFIAB's Suggested Budget</u>	<u>Chairman Ray's Proposal</u>
Reduced Consumption	\$ 5 million	\$ 30 million
Improved Efficiency	105	136
Oil, Gas, Coal	660	563
Nuclear Fission	530	732
Fusion & Other Energy	170	217
Sources		
Manpower Development	<u>30 -</u>	<u>48</u>
Total	\$ 1,500 million	\$ 1,726 million

Although somewhat different in detail, the thrusts of the two proposals are consistent. An exception is the even greater weight given to oil, gas, and coal R&D by PFIAB. (The existence of such a difference may indicate the desirability of frequent reviews of the adequacy of support in this area.)

The PFIAB report also examines both the near-term and more distant promise of oil discovery and improved efficiency of recovery, oil extraction from non-conventional sources, enhanced utilization of coal and gas, nuclear generation, and geothermal and solar energy.

You may be particularly interested in highlights relating to improvements in domestic oil production and the acceleration of oil exploration.

-- We now extract one-third of our oil deposits, but new (fire drive) and old (e.g., hydrofracture) techniques for secondary

recovery might enable us to extract up to another third -- effectively doubling the domestic supply. Some of these methods are proprietary, and we need to consider how to induce cooperation among companies.

- Most continental shelf exploration has occurred at depths less than 100 feet. Accelerated prospecting, search at greater depths, coordinated use of scarce drilling equipment, and faster development of rapid drilling techniques may lead to the discovery of great additional oil supplies in a relative short time.

In connection with management and manpower issues, the report (1) suggests that consideration be given to recruiting the top management for the Energy Research and Development Administration as a team to insure both excellence and compatibility; (2) urges that the fullest utilization be made of the highly competent AEC laboratories; and (3) draws attention to a possible storage of scientific manpower to carry on a vigorous energy R&D program in the 1980's and 1990's.

The Board was not able, in the time allotted, to draw useful comparisons between US and Soviet energy R&D efforts, but intends to follow up on this question.

I have sent a memorandum to PFIAB expressing your appreciation for their useful effort. Information copies of the report have been forwarded to Mr. Simon and Dr. Ray. No further action is required.

THE WHITE HOUSE  
WASHINGTON

MEMORANDUM FOR

Admiral George W. Anderson, Jr., USN (Ret.)  
Chairman, President's Foreign Intelligence Advisory Board

SUBJECT: Report on Energy R&D

The President has asked me to convey his appreciation for the analysis and thoughts in the Board's report on The Energy Problem and for the example of an appropriate FY 75 energy R&D budget.

The President has noted your recommendations regarding the management, priorities, and technical manning of the U.S. energy R&D effort. The material in this report will be a useful reference in addressing the extremely important energy issues which confront us.

The President wishes particularly to thank Dr. Teller and Dr. Foster for applying their talents to these questions.

Henry A. Kissinger

1975 ENERGY R&D BUDGET

1500

TOTAL PROJECTED EXPENDITURES (in millions of dollars)

	Technology	Comments
5	Reduced Consumption	This low figure corresponds to the intention to make minimal use of regulation.
105	Improved efficiency	Can lead to a contribution of more than 10% in the short run.
20	High temperature gas turbine	These two items are related.
15	Topping, bottoming cycles	
30	MHD	We have an agreement to cooperate with the Russians.
5	Waste fuels	More important with regard to waste disposal.
10	Automobile	Should depend on cooperation of Detroit.
5	Submarine tanker	Important alternative to additional Alaskan pipelines.
20	Energy transmission, storage	Help in better energy management.
660	Oil, Gas, Coal	This program is likely to be the biggest contribution in the short run.
50	Secondary recovery, drilling	The amount is modest compared to the importance of the issue. The main contribution should come from the private sector.
20	Control oil spills	This is a critical issue in which little research has been done.
80	Stimulation	The development of cheap sources of gas and better exploitation of residual oil.
150	In situ processing	Important in coal gasification and vital for oil shale
20	Clean coal combustion	Two topics on reconciling energy requirements and environmental standards.
30	Particulate precipitation	
30	Low BTU gas	Conservative approaches connected with coal gasification.
30	High BTU gas	
20	Low to High BTU conversion	

Oil, Gas, Coal (Cont'd)

20	Gas to methanol	}	Approaches to substitutes for oil.
30	Liquefaction (standard)		
30	Liquefaction (advanced)		
40	Underground coal mining	}	Required to make mining acceptable and profitable. Needed to meet environmental objections.
50	Strip mining		
20	Environmental animal exp.		
40	Environmental studies	}	Needed to relax environmental constraints without serious health hazard.
530	Fission		
120	Reactor safety		
80	Uranium enrichment	}	Main future source of electricity. Insure that not a single accident occurs. Probably novel methods will be cheaper. Present scarcity of fuel by exploiting poorer ores.
28	Uranium mining		
120	HGTR		
20	LWBR	}	Hopeful methods to utilize abundant thorium.
30	D <sub>2</sub> O + CANDU		
40	Thorium		
80	LMFBR	}	Presently very popular; should be continued to exploit past investment.
20	Advanced breeders		
170	Fusion + Other		Mixed items of considerable value.
60	Fusion, using magnetic confinement		Main line to attain controlled fusion by slight expansion of present research.
10	Laser fusion		New and imaginative approach; will not move before the year 2000.
30	Solar heating and cooling of buildings		Could save 10% of oil requirements
10	Ocean, Photo-Bio		Exotic methods to use solar energy.
60	Geothermal		Alternate source of electrical energy.
30	Manpower		Needed to insure technical capabilities beyond 1980.

THE WHITE HOUSE

WASHINGTON

PRESIDENT'S FOREIGN INTELLIGENCE ADVISORY BOARD

December 7, 1973

Dear Mr. President:

At our meeting with you on 4 October, we briefly discussed the utilization of federal funds for energy R&D. You requested that the Board submit its recommendations on the dollar-amounts which could be meaningfully applied to individual programs comprising the total energy R&D effort. You also inquired parenthetically what the Soviet Union and other highly developed societies are doing in this field.

The enclosed paper was written by Dr. Edward Teller, with the assistance of Dr. John S. Foster, Jr. It discusses major areas for the application of R&D funds and includes a projected energy R&D budget for FY 1975 amounting to a total of \$1.5 billion. It also discusses a potentially critical shortage of scientific manpower and proposes a unique low-cost solution for meeting the problem.

In light of the prospect that Congress may now approve an energy research and development agency in this session, I believe the following recommendations are particularly important:

-- The senior staff of the energy R&D program should be recruited as a team. This will ameliorate the problem of professional and personnel differences which so often hamper major efforts of this kind.

-- Many of the senior personnel for the energy R&D agency will have to come from private industry.

-- In designing the research programs, greatest priority should go to short-range programs with a payoff established before 1980. This still permits emphasis on imaginative new programs.

-- Recruitment of technical manpower for the emerging needs of the government laboratories should receive early attention.

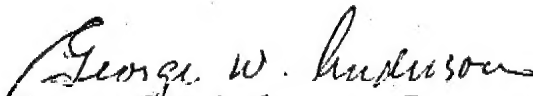
We are unable to adequately answer your question with respect to what other nations are doing in the energy field. We have levied

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a requirement on the Intelligence Community for continuing information on specific energy R&D programs being undertaken abroad, as well as for information on the impact of energy on foreign economic and diplomatic policy. Your energy message of April 18, 1973 has anticipated the great present need. It should now be followed up by a plan for cooperation with our allies, particularly in research. The State Department has been taking initial steps in this direction. We suggest that you encourage a rapid follow-up on this action.

I have taken the liberty of sending a copy of this report to the Chairman of the Atomic Energy Commission, Dixie Lee Ray, and to the Administrator of the Federal Energy Office, William E. Simon.

Respectfully yours,

  
George W. Anderson, Jr.  
Admiral, USN (Ret.)  
Chairman

The President  
The White House  
Washington, D. C.



## THE ENERGY PROBLEM

### Reasons and Effects of the Energy Shortage.

Oil has become the most widely used energy source because of its availability and easy transportation. This in turn has led to a development of an infrastructure which depends on oil. Thus an oil shortage necessarily has painful and worldwide consequences. Just such a shortage is developing.

While the per capita energy consumption is increasing in the United States the main reasons for the shortage lie outside the United States. One is the rapid recovery of Western Europe and of Japan and the increased energy demand that has gone with this recovery. Another is the anticipation of the increasing energy demands in the developing world. Greater care in the use of energy can help, but this is merely a palliative. The predictable increase of energy requirements will almost certainly create a severe shortage of oil before the end of this century.

Since domestic production of oil and gas has not been available in sufficient quantity using conventional methods, the United States has increasingly turned to foreign imports. The adverse effects of continuing to do so, both in a financial sense and in a political sense, are becoming obvious.

### The Question of Timely Response.

The actions and solutions which we consider can be subdivided into short range, medium range, and long range plans. Without trying to be precise, I want to consider the planning for the 1970s as short range planning, the planning for the 1980s and 1990s as medium range planning, and the planning for the next century as long range planning. All three are necessary, but each has different characteristics.

Short range plans are fiscal, political and regulatory in nature. At the same time questions of management have to be settled in the short term and elements of technology will play an important part in making the appropriate choice. Decisions concerning the short-range plans are not only the most urgent, but probably also the most difficult.

Medium range plans are connected with technical developments where the solutions are either available or at least can be anticipated with reasonably high probability. While the lead-time in technology is necessarily of considerable duration, medium range plans can become effective by proving (even before the year 1980) that new and relatively inexpensive energy sources will become available. In case this can be demonstrated, the anticipated price of oil may decline and it will be in the interest of the oil-rich countries to sell their oil before the new energy sources are fully developed.

The long-range planning is concerned with technical solutions which are desired, but are difficult. In many cases even their feasibility is in question. Furthermore, the question whether and to what extent the long-range solutions will become necessary depends on the success achieved in the medium range. Important examples of this last category are the massive use of solar energy (in contrast to the short-range possibility of heating and cooling small houses by solar energy), the development of fast breeder reactors, and the realization of economic controlled fusion. From a scientific and technical point of view the solutions of these problems are the most exciting, but they cannot be expected to solve our present urgent problems. This planning should be pursued and the corresponding research should be supported as an insurance for the future. On the other hand, no crash program on long range technologies seems to be justified. Correspondingly, these problems will not be discussed in great detail.

#### The Question of Management.

The success of the whole program depends primarily on the excellence of the people involved in it. While it is impossible to give a general description how to select these people, and how to operate the system, a few remarks might prove useful.

The first task is to secure excellent leadership. Half a dozen people in top positions can make sure that the staffing is of high quality on all levels. It seems necessary for the President not only to select the members of this top echelon, but also to make the appointments in consultation with the President's top administrator and in subsequent consultations with the candidates on the jobs serving immediately below that administrator. By the proper formation of

this leadership group it may be possible to insure the essential smooth cooperation between its members and a proper subdivision of the complex task which they have to accomplish.

It is an important question whether the bulk of the people who will serve in the organization shall be drafted or whether preference should be given to those who are eager to serve. The answer is not obvious to me, but I tend to favor the alternative of voluntary service.

Of all the existing governmental agencies the AEC has the most firmly established history in imaginative and massive research producing novel results. It seems, therefore, appropriate to use the experience of this branch of the government as a model. The manpower of the AEC may be considered as one of the sources from which to draw the personnel for the energy administration. This contingent will have to be balanced by people drawn from the oil and coal industries and from corresponding governmental agencies.

It is of great importance to delegate most of the actual research work to government laboratories. This has proved effective in the work of the AEC, and also in the USGS. The best results are produced when the laboratories are entrusted with the planning of their own work, as well as with the execution of these plans. The central agency in Washington has the extremely important task of supervision, of making the funds available, and of balancing the long-range objectives. This type of operation has the double advantage of on-the-spot expertise and a reasonable measure of competition between the different laboratories. The central agency can make sure that this competition does not degenerate into uncontrolled duplication.

Finally attention must be given to the transfer of technology from the government laboratories to industry. This may be initiated by Washington but will have to be executed by the people directly concerned. A transition phase of a joint endeavor (which might be started early in the game) may be an effective procedure.

#### Accelerated Exploration for Oil.

Exploration for oil is the way in which additional supplies can be made available in the shortest possible time. In the United States the most hopeful

additional discoveries are likely to be made on the continental shelf. So far most explorations have occurred at a depth no greater than 100 feet. The search should be intensified at greater depths and there is a considerable probability that substantial amounts of oil will indeed be found. Furthermore, additional exploration is needed throughout the world and such exploration is the best early hope to bring about a change in the present worldwide shortage. There are, however, several problems which will have to be faced at the same time.

The problem of oil spills has made it difficult to proceed with exploration on the continental shelf surrounding the United States.. The solution of this problem lies in part in the reliably enforced regulations that will make oil spills very improbable. A second technological aid is the development of methods to clean up oil spills in the few cases in which they occur. Research on this topic is badly needed and should give proper confidence which will allow us to proceed with the exploration.

Another problem is the scarcity of drilling equipment which could worsen if steel shortages develop. Coordination between the oil companies of the free world may help. This could also have an effect to offset the impact of OPEC and more particularly the impact of the Arab boycott.

Undersea exploration throughout the world is an even more ambitious undertaking and one that is badly needed. The technological expertise of the U.S. added to the expertise of our allies could bring about a most welcome change. In this connection the political question of territorial rights extending three miles, 12 miles or further from the shoreline will play an important role.

One special case of great interest is the Persian Gulf. Approximately one-half of the Gulf is closer to Iran than to any other country. Apart from the international questions mentioned in the previous paragraph, our friendly relations with the Iranians should make it relatively easy to open up this territory. Because the area is so rich in oil the exploration may take a relatively short period and in less than a year highly favorable results may be obtained. It is, of course, of great importance to obtain agreements

whereby one could guarantee that any oil discovery will remain available at some reasonable price for a period like 10 years. Beyond that time I hope that there will be other energy sources available and the worst of the shortage may be over.

A strong reason to advance such drillings is to stake out claims in view of the developing arrangements of sea-bottom usage. Joint work by the Western industrialized countries with full support from the governments could have considerable leverage.

One additional technical question is the development and deployment of rapid drilling techniques. Fortunately, such techniques are beginning to become available. Their rapid and general implementation and further development would be particularly important on the continental shelf where the time spent in drilling is a major factor in determining the cost of the exploration.

#### Possible Improvements in Domestic Oil Production.

According to present methods of our domestic oil production we are recovering only one-third of the oil of which we know. Two-thirds remain under the surface, (the percentage that is available for cheap pumping in the Middle East happens to be much higher).

Oil companies are engaged in improved recovery methods. One very promising procedure that is being developed is the "fire drive". Air is pumped into the oil field from one well, the oil is ignited, and the product is pumped out from a neighboring well. Thus, the fire front is driven from the first well toward the second. The heat generated decreases the viscosity of the oil. The carbon dioxide produced in the burning is driven ahead of the flame, gets dissolved and probably makes an even greater contribution to the decrease in viscosity. This method added to the older techniques of hydrofracturing, use of explosives and use of surfactants will result in more oil which can be removed. Optimistic estimates would allow a removal of the second one-third of the underground oil, leaving altogether only one-third of the original deposit unrecovered.

The work carried out by several oil companies is proprietary. Thought should be given to the question in what way one could induce the oil companies to cooperate on this problem which is of obvious national importance.

Our known recoverable reserves at \$3.50 per barrel are less than 40 billion barrels. The additional amount that could be made available from U.S. sources by the methods mentioned (improved secondary recovery and new discoveries) may well be 300 billion barrels producible at the wellhead. This amount is almost as great as the known Arab reserves.

The methods of improved oil production are becoming effective in a gradual manner. Therefore, in this case we have a contribution to the energy resources which could in part have a short term impact. A considerable fraction, however, is to be expected in the medium term.

#### Solar Heating and Cooling.

The idea to use solar energy has been accepted with enthusiasm by the public and the politicians. The energy source is ample, inexhaustible and completely clean. In this case we are faced with the peculiar situation that a part of the energy could be made available almost at once, while other applications will probably not become economical in the short term or medium term.

The difficulty with solar energy is that it is dilute. Its massive application requires methods to concentrate the energy and these methods are expensive. On the other hand the wide distribution of the energy makes it possible to employ it in heating and in cooling of houses, provided the structure is not more than three stories high.

The method is relatively simple. It essentially depends on heating water and using the hot water to store the energy. Air conditioning can likewise be accomplished without using electricity, for instance, by employing interaction of ammonia (used, of course, in a closed cycle) with hot and cold water. The method appears to be financially attractive in the lower half or the lower two-thirds of the United States. Considering this limitation and considering also the restriction to low buildings, one can expect that this method could eventually replace 10% of our fuel requirements. By 1980 we can hardly expect more than 5%. Difficulties will be encountered due to the inertia of the building industry. However, the popularity of solar heating is so great that one might hope to overcome these difficulties. Otherwise, the technology is "state of the

art" and the main effort should be directed toward faster production and wider acceptance of the product.

Proposals have been made to generate electricity by concentrating solar light in the southwestern United States. The capital investment needed for this undertaking is probably three times as high as the capital investment for nuclear reactors. Improvements are not likely to occur rapidly, partly because the usual methods of concentrating solar energy (the use of mirrors and of the greenhouse effect) are inherently expensive and partly because novel methods (direct photoelectric generation and the imitation of the photosynthesis in plants by chemical methods) is truly adventurous. One cannot expect that these methods will pay off before 1980 and it is much more probable that economic benefits will occur only in the next century.

#### Conventional Coal Gasification and Coal Liquefaction.

In this section I shall discuss the mining of coal and its subsequent conversion into gas or liquid fuel.

The most ample supply for these processes (particularly for low sulphur coal) is found in the Rocky Mountain area. Its distance from our industrial centers is a slight disadvantage due to the transportation costs of coal. In case of local coal gasification or coal liquefaction, this disadvantage is decreased.

The cheapest method of coal production is strip mining. Objections of environmentalists can be met in part by rehabilitating the vegetation following the mining operation. In arid regions this rehabilitation may be difficult and expensive. Selective prohibition, however, should depend on local conditions, particularly on meteorological conditions.

It is estimated that coal gasification by the Lurgi process (burning the coal in oxygen at high pressure in the presence of water) will produce high BTU gas at approximately \$1.5 per million BTU.

More advanced technologies already under development might lower this price to one dollar. This might be cheaper and it would certainly be more reliable than some of the planned foreign purchases. If air is used instead of oxygen, a clean low BTU gas will be produced at two-thirds of the price (70¢ to



\$1 per million BTU). Although its transportation costs would be too high for distributed use, this gas could be produced from high sulfur coal at power plant sites where it would be an excellent fuel. These processes would yield cheaper gas than is obtainable from abroad.

It is relatively inexpensive to transform the obtained gas into a liquid consisting chiefly of methanol. It is claimed that methanol burns in a much cleaner way in cars than any conventional oil. An objection to this statement might be found in the production of small amounts of harmful formaldehyde. This point requires engineering research and biological research. The retooling of cars enabling them to burn methanol is relatively minor. One disadvantage is that the energy in this fuel is less than that of gasoline per unit volume of fuel. Therefore, cars will have to be filled up more frequently or bigger tanks will be required.

It is also possible to polymerize the gas and obtain a product similar to gasoline. This procedure is being followed in South Africa, who have produced for some time approximately one-tenth of their gasoline needs in this manner. The cost of sulfur free fuel is approximately \$6 per barrel, as proved in engineering practice. The price holds for South Africa where coal is cheap and the capital investment has been mostly written off.

Improvements of coal liquefaction may be obtained by dissolving the coal in an organic liquid, freeing it of its ash content and from its sulfur content, and hydrogenating the coal without first gasifying it. The hydrogen probably has to be obtained from a coal gasification process. There is some expectation that this process will turn out to be less expensive than the one practiced at present in South Africa. Even so, it will be difficult to produce oil in this way for \$6 per barrel in the U.S.

In the process just described one may stop short of hydrogenation and simply precipitate the coal from the solution after it has been purified. This would give a solid fuel more expensive but cleaner and having higher energy content than the original mined coal. Other methods of cleaning up coal have also been proposed.

Of the processes described above, standard coal gasification, the production of methanol, coal liquefaction as practiced in South Africa and coal purification



are reasonably well known and might give some contributions at a substantial cost before 1980. The other possibilities should be considered as medium range solutions.

While the fuel obtained in this manner may be rather expensive it could eventually be made available in great quantities.

#### In Situ Coal Gasification:

It has been suspected for a long time that coal gasification can be carried out underground much less expensively. The main process, burning the coal in oxygen under pressure and in the presence of water, does not necessarily require the prior removal of the coal from the ground. Experiments of this kind have been carried out, particularly in Russia. They were usually performed in coal mines and they were unsuccessful, partly because the mines were shallow and a sufficient pressure could not be maintained, and partly because the fire burned out of control.

A new and hopeful process would consist in the exploitation of deep and thick coal seams. The depth may be between 500 feet and 3,000 feet, the total thickness at least 50 feet. Deposits of this kind are found in Wyoming, Montana and other areas.

A considerable number of one or two-ton conventional high explosives would be detonated within the coal seam. The process is to reduce the coal-bearing layer to rubble with approximately 25% void space. Oxygen would be pumped down, the coal would be set on fire and an appropriate amount of water poured over it. The rate at which oxygen is made available will control the burning. The head of water provides the pressure. If the burning is started at the top of the formation and the gas formed is drawn off from the bottom, a uniform flame front and rather complete burning is expected.

Pilot operations should start simultaneously in several places since success depends on various factors: the depth and composition of the deposit and the nature of the material occurring together with the coal which may affect both the burning process itself and the distribution of the products, the latter being influenced by the catalytic action of materials occurring in the coal bed.

Considerable work is being performed on thinner coal beds where the burning proceeds in a horizontal direction and a sizable fraction of the coal is left behind. This method gives low BTU gas at a cost probably less than 50¢ per million BTU. The most important fact is that the relevant thin coal seems to have a wide distribution throughout the world.

It is estimated that the in situ process may cost as little as 50¢ for a million BTU. The amounts available would be very large, the objections against strip-mining would not apply and a really satisfactory solution of the gas problem may be at hand.

Unfortunately, the process is untried, the performance of various formations may be quite different and a development time of several years must be anticipated. Sizeable production can not be expected even in the best case before the early 1980s. On the other hand, a proof of the functioning of this method could have a decisive effect on the world market.

The relatively inexpensive and abundant gas which would be obtained could be also converted into methanol or polymerized into a substance resembling gasoline. Therefore, in situ coal gasification, if proven, could have a truly world-wide impact and may solve a major portion of the energy problem.

#### Stimulation of Tight Gas Formations.

Prior to the availability of the products from in situ coal gasification, some additional gas may be found, particularly on the Continental Shelf. Furthermore, we have sufficient known additional gas reserves in tight formations which will not produce gas by conventional methods. It is probable that gas can be produced from these by extensive hydrofracturing. The estimated cost is between 50¢ and 80¢ per million BTU.

Experiments have been carried out on gas stimulation by nuclear explosives. This method is practically proven and could go into full production by 1978. Contributions can be expected at earlier times. This method could provide us with an adequate gas supply for approximately 10 years at a price similar to the one given for hydrofracturing.

In comparing the two methods one should note that hydrofracturing on the scale proposed has not been tried while nuclear experimentation is available. On the other hand if nuclear gas stimulation is to proceed, political opposition will have to be overcome and some technical problems must be worked out. In order to overcome the political opposition it is necessary to maintain a perfect safety record and to minimize radioactive side effects. We are very far along on the road to demonstrate that both these problems can be solved. However, the political opposition is vigorous and an educational campaign, as well as excellent performance, will be necessary to overcome it.

In view of the importance of the question and the unavailable uncertainties of the cost predictions both methods should be explored.

#### The Role of Oil Shale.

According to present knowledge the United States possesses the richest oil shale deposits. This oil shale contains approximately 15% hydrocarbons in a solid form. Our single biggest deposit is in the Piceance Basin in the northwest corner of Colorado, containing approximately twice as much hydrocarbon as all of the Middle East.

There are three methods by which this oil shale could be exploited. I want to designate these as the conventional method, the improved method and the nuclear method.

In the conventional method the shale is strip-mined, or mined from shallow deposits. The shale is then retorted. Air is introduced into the retort from above; the flame is progressing downward. As the flame approaches a layer the volatile hydrocarbons escape and are sucked out from the bottom of the retort. They are then condensed at normal pressure and processed in a manner which will effectively eliminate the sulfur contained in the fuel. The estimated cost of the procedure is \$6 per barrel. The advantage of the procedure is that it is tried and reliable.

The conventional method has also some disadvantages. One is the relatively high cost. Another is that only the shale close to the surface can be economically exploited. This reduces the available amounts. The third and perhaps most serious objection is that the 85% residue which is left over after the retorting

constitutes a major environmental nuisance. If shale is to be used as an important resource in solving the energy problem, we will be left each day with thousands of tons of shale on our hands. Areas covered by shale are extremely difficult to rehabilitate.

The improved method is a form of in situ processing. First shale is removed underground from a room of perhaps 30' x 30' x 15'. This shale is conventionally retorted. Then long holes are drilled into the roof of the room, high explosives are placed in the holes and the roof is caused to collapse. A rubble chimney is thus formed with approximately 25% empty spaces. Then this chimney is treated like an underground retort. The volatile hydrocarbon being sucked off from the bottom of the zone, pumped to the surface and treated. The same process on a bigger scale is also considered.

The advantages of this method are: reduced cost, \$4 to \$5 per barrel of de-sulfurized oil (which is fully competitive at present prices), greater amounts of available shale, and a reduction of the shale brought to the surface by a factor 4.

The Occidental Oil Company is exploring this procedure. One of the potential difficulties may be raised by the presence of ground water.

The nuclear method is similar to the one described above, but carries the process one step farther. A nuclear explosive of perhaps 100 kilotons is exploded under the oil shale at a depth of approximately 2,000 feet. The explosion blows a hole of 200 feet in diameter. This hole takes the place of the room excavated in the previous method. The roof collapses without any further application of high explosives, and a huge rubble chimney is formed of an approximate height of 800 feet. One may then proceed with the retorting as in the previous method.

This procedure has thus considerable advantages. It can exploit a very great fraction of the shale that is underground including deposits not mineable. The estimated cost is somewhere between \$2.50 and \$4 per barrel. And finally, no shale is brought to the surface and, therefore, no major environmental nuisance is encountered.

The difficulties are also great. All the development still lies ahead of us. We have to be extremely careful about complete containment of each nuclear explosion, and the ground water problem may become more serious because of the greater extension of the rubble chimney. Finally, political and emotional objections will be predictably powerful.

The exploitation of oil shale may well become the best method of solving the major portions of the energy crisis in the relatively near future. One can easily understand the dimensions of the promise of oil shale by stating that the eventual value of the oil shale in the Piceance Basin will in all probability exceed a trillion dollars.

Massive exploitation of this oil shale will not occur before the 1980s. The establishment of a relatively low production price of oil from this resource may have a profound effect on the world market and this effect may occur, as research succeeds, by the later 1970s.

#### Other Fossil Fuel Supplies.

It is important to realize that a great variety of coals and hydrocarbons exists underground and may be exploited with appropriate techniques. Two particularly extensive deposits occur in Canada. One is a field of coal and shale-like substance in New Brunswick. The other is a well-known tar sand deposit near the Athabasca River in Alberta, Canada. The recovery method must be suited to the nature of the deposit and in each case a new technology may have to be developed.

In New Brunswick one may attempt to use a recovery method similar to underground coal gasification and involving water. On the other hand, one might consider an approach similar to the one considered for the oil shale in the Piceance Basin in Colorado which is retorting in the absence of water. We probably are at the very beginning of the research that might lead to practical use.

The circumstance that these rich deposits are in Canada rather than in the United States would indicate that we might consider research leading to their exploitation with a lower priority. On the other hand, the energy shortage is a world-wide phenomenon, and cooperative research would probably

be in the interest of Canada, the United States, and other energy-poor countries.

### The Problem of Electricity.

Today 25% of our fossil fuel consumption is used to produce electricity. There is every reason to find alternative methods (i.e. not using fossil fuels) to produce electric energy. To the extent that this can be done in an economical fashion, it would be useful to increase the use of electricity and correspondingly to reduce the burning of fossil fuels. Of course, new types of electrical generation cannot be introduced in a very short time and the increased applications of electricity will also have to occur in a gradual manner.

One must realize that a good solution of the problem how to generate electricity in a manner that is safe, clean and inexpensive (particularly with regard to the fossil fuels) is the smaller part of the energy problem. It remains, however, an important portion.

### More Efficient Production of Electricity.

To the extent that fossil fuels will continue to be used in generating electricity it is important to use these fuels in the most efficient manner. This will mean savings in fossil fuels. It also brings about considerable reduction in the so-called thermal pollution.

There are in principle two ways in which the efficiency of the generation of electricity can be improved. One is that in converting the heat energy produced by the fossil fuel into electricity one should start at a higher temperature. The other is to reject the spent thermal energy at a lower temperature. The first may be accomplished by a "topping cycle", the second by a "bottoming cycle". The latter is important when the exhaust has a temperature of 600°F or more.

Topping cycles can use gas turbines, provided materials resisting high temperatures can be used. Alternatively, one might use a magnetohydrodynamic (MHD) generator in which the kinetic energy of expanding gases is transformed directly into the energy of an electric current.

Among the bottoming cycles (which are of lesser importance) I would mention a "steam engine" in which the steam of water is replaced by the steam of an appropriate sealed-in organic fluid which can operate effectively at a lower temperature than water vapor. This bottoming cycle could be used with particularly great effectiveness in conjunction with gas turbines which generally operate at a rather high temperature.

Today, the best electric plants operate in the neighborhood of 40%. It should be possible to raise this figure to 60%. Incidentally the "thermal pollution" will be reduced at the same time by more than a factor 2.

#### Geothermal Heat.

There exists an ample heat reservoir under our feet at varying depths. It is possible to convert this heat into electricity. Three examples will be briefly reviewed.

There are some places where one can obtain from the underground reservoir relatively high temperature dry steam. Well-known examples occur in Italy, New Zealand, and also in California. This energy resource appears to be not very abundant, but can be used quite effectively.

A more abundant energy source is available in many locations of Western United States in the form of moderately high temperature (600°F) highly saline solutions. One can drill down to these hot water reservoirs. Having relieved the pressure the water will boil and eject wet steam charged with salt and other particles. It is possible to utilize the heat of this water in a turbine which transforms the impact into a rotary motion and has a 20% efficiency (an almost two-fold improvement on present technology). The problem is to find appropriate materials to withstand the effects of abrasion, corrosion and scaling produced by the mixture of the impinging vapor, liquid and particles. It is hoped that a few years' research will make the energy resource available and energy should be produced at a competitive price. (Between 7 and 10 mills per kilowatt hour.) A sizeable fraction of our electric requirements might be covered in this way.

The most abundant geothermal resource is in dry rock. This is also the resource which is hardest to utilize. Successful exploitation is not very

likely before the year 2000.

### Electricity From Nuclear Reactors.

The most obvious means to meet our demands of electricity without using fossil fuels is to construct nuclear reactors. Thorough research extending over the last 30 years has effectively solved the problem of controlled fission, both in principle and in practice. The use of nuclear reactors has also the great advantage of effectively complete cleanliness. Objections have, however, been raised against reliance on these reactors. One is the assertion that reactors are dangerous, the second is the claimed circumstance that we shall run out of nuclear fuel for presently developed designs.

There are four claimed adverse effects of nuclear reactors: the low-level radiation emitted by these reactors, thermal pollution, dangers connected with disposal of nuclear wastes and the danger of a major nuclear accident. The first three of these claimed difficulties are either insignificant, or satisfactory solutions are available at the present time.

The danger of a major nuclear accident is exceedingly unlikely, but because of its catastrophic consequences (many thousands of people might die, due to the radioactivity released from the reactor) the problem must be taken seriously; I consider present methods safe enough to prevent any major accident, but one still must continue to work on further improvements of safety. Indeed, a single major accident will result in strong demands that all reactors be closed down.

There are three available methods of further increase in reactor safety. One is the choice of particularly safe reactor types such as the high temperature gas-cooled reactor, or the heavy water moderated Canadian CANDU reactor. Another method is distant location of reactors on reactor "farms". This requires work on cheap electrical transmission over long distances; there is effective research directed toward this goal. The final method is to place reactors underground.

An important related political problem is to streamline the reactor licensing procedure. Today reactor construction takes 8 to 10 years. This time could be cut in half if the licensing procedure could be simplified. This, of course, can be properly done only if at the same time real progress is made toward safer reactors.



The second objection against nuclear reactors is that we are going to run out of nuclear fuel. Fortunately, the safest reactors (high temperature gas-cooled and CANDU) lend themselves to thorium breeding. According to present designs we could replace 80% of uranium by cheap and abundant thorium. Gradual improvements in the design will lead without great difficulty to substantial increases in the percentage that thorium would play in the fuel economy.

At the same time there is reason to do more research on extracting uranium from abundant minerals which contain a small percentage of uranium. This, together with the proposal of the previous paragraph, should solve the nuclear fuel problem at least for the next century.

#### The Problem of Manpower.

The above discussion was roughly arranged in terms of the timeliness of the response. There seem to be abundant alternatives to obtain a solution of the energy problem in the last two decades of the century. This requires, however, considerable research. While scientific manpower is available at present, in the 1980s and 1990s a shortage is apt to develop. If that happens our research will be limited more by the availability of manpower than by the availability of funds.

The reason for this situation is that in the last 10 years education in science and technology has become unpopular at our universities. The trend seems to have stopped but an increased interest in the most important field of applied science has not yet developed to the needed extent.

The problem could be met in part by support of work on engineering, applied science, and also pure science at our universities and institutions of technology. While this measure is needed, it is not likely to suffice by itself because the antitechnology trend is strongly represented in the faculties of our leading institutions. It is obvious that the Government can offer only inducements and cannot impose decisions on our institutions of higher education. All this is unfortunate because our universities have an effective monopoly on higher education.

One should, therefore, consider an alternative approach. The main educational function has to be carried out on the graduate level. Here existing

applied science laboratories could be of great help. Excellent laboratories of this kind are found in the private sector (like the Bell Telephone Laboratories and the laboratory of IBM) and in the governmental sectors (like the laboratories of the AEC). These and similar laboratories should be encouraged to provide graduate education in institutes attached to the laboratories. It is important that these institutes should be given the right to grant high degrees. The teaching manpower and the equipment needed for the education is available and the enterprise could be carried out at minimal cost.

A desirable effect would be the breaking of the monopoly of the universities. As a result the universities themselves are likely to become more interested in applied science. I believe that competition would be a healthy influence.

#### The Cost of Needed Research and Development.

Some of the proposals discussed in this paper will become feasible only after an appropriate amount of research has been performed. Even when methods are known, further research is to be recommended to improve the process with respect to quantities that can be made available, with respect to price, and often with respect to environmental impact.

Thorough studies are being made at present about needed expenditures and this note can not claim to be nearly as well founded as official estimates. However, I am including figures which were drafted along similar lines as the proposal of the AEC. The purpose is to give a quantitative indication of the importance of the various items.

The budget is suggested only for fiscal 1975. Results obtained in the first year should have considerable bearing on further plans.

Comments are attached to elucidate the significance of individual items on the budget.

1975 ENERGY R&D BUDGET

1500

TOTAL PROJECTED EXPENDITURES (in millions of dollars)

	Technology	Comments
5	Reduced Consumption	This low figure corresponds to the intention to make minimal use of regulation.
105	Improved efficiency	Can lead to a contribution of more than 10% in the short run.
20	High temperature gas turbine	These two items are related.
15	Topping, bottoming cycles	
30	MHD	We have an agreement to cooperate with the Russians.
5	Waste fuels	More important with regard to waste disposal.
10	Automobile	Should depend on cooperation of Detroit.
5	Submarine tanker	Important alternative to additional Alaskan pipelines.
20	Energy transmission, storage	Help in better energy management.
660	Oil, Gas, Coal	This program is likely to be the biggest contribution in the short run.
50	Secondary recovery, drilling	The amount is modest compared to the importance of the issue. The main contribution should come from the private sector.
20	Control oil spills	This is a critical issue in which little research has been done.
80	Stimulation	The development of cheap sources of gas and better exploitation of residual oil.
150	In situ processing	Important in coal gasification and vital for oil shale
20	Clean coal combustion	Two topics on reconciling energy requirements and environmental standards.
30	Particulate precipitation	
30	Low BTU gas	Conservative approaches connected with coal gasification.
30	High BTU gas	
20	Low to High BTU conversion	

Oil, Gas, Coal (Cont'd)

20	Gas to methanol	}	Approaches to substitutes for oil.
30	Liquefaction (standard)		
30	Liquefaction (advanced)		
40	Underground coal mining	}	Required to make mining acceptable and profitable.
50	Strip mining		Needed to meet environmental objections.
20	Environmental animal exp.		Needed to relax environmental constraints without
40	Environmental studies		serious health hazard.
530	Fission		Main future source of electricity.
120	Reactor safety	}	Insure that not a single accident occurs.
80	Uranium enrichment		Probably novel methods will be cheaper.
29	Uranium mining		Present scarcity of fuel by exploiting poorer ores.
120	HGTR		Hopeful methods to utilize abundant thorium.
20	LWBR		
30	D <sub>2</sub> O + CANDU		
40	Thorium		
80	LMFBR		Presently very popular; should be continued to exploit
20	Advanced breeders		past investment.
170	Fusion + Other		Mixed items of considerable value.
60	Fusion, using magnetic confinement	}	Main line to attain controlled fusion by slight expansion of present research.
10	Laser fusion		New and imaginative approach; will not move before the year 2000.
30	Solar heating and cooling of buildings		Could save 10% of oil requirements
10	Ocean, Photo-Bio		Exotic methods to use solar energy.
60	Geothermal		Alternate source of electrical energy.
30	Manpower		Needed to insure technical capabilities beyond 1980.